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(54) Title: INJECTABLE CERAMIC COMPOSITIONS AND METHODS FOR THEIR PREPARATION AND USE

(57) Abstract

Injectable implant compositions comprise a biocompatible ceramic matrix present in a fluid carrier, where the ceramic matrix comprises particles having a size distribution in the range from 50 μm to 250 μm. Optionally, the compositions may further comprise collagen, where the relative amounts of collagen and ceramic matrix at least partly determine the physical properties of implants formed by injecting the compositions. The fluid carrier is an aqueous buffered medium, typically including an organic polymer base material when there is no collagen present in the composition. The compositions are particularly suitable for repair and augmentation of soft and hard tissues by injection.

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INJECTABLE CERAMIC COMPOSITIONS AND METHODS FOR THEIR PREPARATION AND USE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to the preparation and use of biocompatible implant compositions. More particularly, the present invention relates to injectable ceramic implant compositions for soft and hard tissue repair and augmentation.

The use of collagen compositions for tissue repair and augmentation is known. The collagen may be utilized in a variety of forms, including cross-linked and non-cross-linked fibrillar collagens, gelatins, and the like, and may be combined with various other components, such as lubricants, osteogenic factors, ceramic particles, and the like, depending on the intended use. For soft tissue repair, suspensions of fibrillar collagen have often been used by injecting the composition to a treatment site through a fine gauge needle. For bone and hard tissue repair, fibrillar collagens have been combined with the ceramic powders, such as hydroxyapatite and other calcium phosphates. These compositions, however, have not been injectable.

The use of fibrillar collagen as the primary matrix material in injectable soft and hard tissue implant compositions has several limitations. The preparation of fibrillar collagen suitable for human use is relatively time consuming and expensive. In particular, the complete removal of contaminating and potentially immunogenic substances to produce "atelocollagen" is a relatively complex and expensive procedure. Moreover, the persistence, shape retention, cohesiveness, stability, elasticity, toughness, and intrudability of the fibrillar collagen compositions could be improved.

Heretofore, fibrillar and other collagens have been used primarily for superficial soft tissue augmentation, i.e., near the surface of the skin. For deep tissue injection, particularly to locations near bone and cartilage, the use of cross-linked collagens is problematic, and the use of non-cross-linked collagens is ineffective.

One approach for improving the compositions utilized for soft and hard tissue repair and augmentation would be to at least partly replace the fibrillar collagen in such formulations with a ceramic mineral material, particularly with hydroxyapatite or other calcium phosphate minerals. Hydroxyapatite has very low immunogenicity.

The incorporation of such mineral particles in compositions intended for soft and hard tissue treatment, however, has been found to be ineffective due to the difficulty in introducing such compositions to the treatment site. In particular, the incorporation of generally available ceramic mineral particles inhibits or prevents the introduction of the compositions through a fine gauge needle to the tissue site of interest. Thus, injectable ceramic implant materials have generally not been available and any benefits which may derive from their use remain speculative.

It would therefore be desirable to provide improved injectable implant materials for soft and hard tissue repair and augmentation where at least a portion of the primary tissue matrix substance is a biocompatible ceramic material. Such compositions should be readily injectable so that they can be introduced to a desired soft tissue site using a fine gauge needle. In addition, such compositions should be persistent at the site of injection, preferably adhering to the soft tissue into which they have been injected; they should be stable, i.e. undergo no significant changes *in situ*; be tough and elastic, i.e. be capable of bearing loads without

undergoing excessive or permanent deformation; be non-toxic and well-tolerated by the body, i.e., produce no or tolerable levels of immune and inflammatory responses; and be intrudable, i.e., form a relatively dispersed, irregularly shaped mass within the tissue where the composition has been introduced. In particular, the improved implant materials should be suitable for deep tissue injection, particularly to locations near bone and cartilage, for purposes such as sphincter repair, nasal repair, and the like. It will be appreciated, of course, that the compositions and methods of the present invention while meeting at least some of these objectives, will not necessarily meet each of these objectives in every embodiment.

2. **Description of the Background Art**

Compositions comprising collagen and a mineral material, such as hydroxyapatite or tricalcium phosphate, are known for use in repairing bone defects. See, for example, U.S. Patent Nos. 5,001,169; 4,992,226 (which is a division of 4,795,467); 4,865,602; 4,776,890; and 4,563,350. Lemons et al. Second World Congress of Biomaterials, April 27 - May 1, 1984, reported the use of collagen and hydroxyapatite/calcium phosphate compositions to repair bone lesions in rabbits. A soon to be commercially available composition with the trade name COLLAGRAFT (Zimmer, Inc., Warsaw, IN) comprises highly purified bovine dermal collagen which is combined with hydroxyapatite and tricalcium phosphate at a ratio of about 1:15 collagen: ceramic by dry weight. Such collagen and mineral formulations are generally not injectable through a small diameter needle and have not been employed for soft tissue repair.

U.S. Patent No. 4,803,075, describes collagen compositions including a lubricant material to enhance injectability through narrow diameter needles for soft tissue repair. U.S. Patent No. 4,863,732, describes an injectable composition comprising collagen and an

osteogenic factor suitable for bone repair. POLYTEF® Paste (Mentor Corporation, Santa Barbara, CA) is an injectable paste composition comprising pyrolyzed poly(tetrafluroethylene) particles present in glycerin with a small amount of polysorbate 20 suitable for tissue repair of the larynx.

Hydroxyapatite layers on various surgical implants have been found to enhance bonding to soft tissue in a host. Hench, "Bioglass Implants for Otology," in: *Biomaterials in Otology*, Grote, ed., pp. 62-69, Martinus Nijhoff Publishers, The Hague (1983).

The full disclosures of each of these references are incorporated herein by reference.

SUMMARY OF THE INVENTION

The present invention comprises injectable implant compositions which incorporate biocompatible ceramic particles as a primary matrix material. The ceramic matrix particles are sized within a range selected to enhance injectability and minimize immune and inflammatory response and are present in a pharmaceutically acceptable fluid carrier, typically an aqueous media which optionally includes an organic polymer to form a gel for suspending the ceramic particles. Compositions may further comprise fibrillar collagen as a co-matrix material, where the ratio of ceramic matrix to collagen matrix is selected to provide for a desired consistency or firmness in the resulting implant.

The use of biocompatible ceramic particles as a primary matrix is advantageous in a number of respects. The ceramic particles are able to become anchored within a host's own tissue, resulting in a very persistent implant which remains stable over extended time periods. Despite this ability to interact with the host tissue, the ceramic matrix particles are substantially immunologically inert and cause little or no immune or inflammatory response. Further, by selecting resorbable

or inert (non-resorbable) ceramic materials, or combinations thereof, the long-term persistence of the implant can be programmed depending on the particular application. Additionally, the ceramic matrix materials are inexpensive relative to other matrix materials, such as collagen, thus reducing the cost of the compositions of the present invention. Moreover, by employing collagen as a co-matrix material, soft tissue implants having a wider range of consistency or firmness can be achieved than with either the ceramic matrix or collagen matrix alone. Surprisingly, these benefits are achieved while the compositions remain readily injectable, facilitating the preferred use in soft tissue repair and augmentation.

The present invention further comprises methods and kits for preparing such compositions, where the ceramic matrix particles having the requisite size distribution are combined with a fluid carrier and optionally with fibrillar collagen and/or other components. Usually, the kits will comprise prepared compositions in ready-to-use syringes.

The present invention still further comprises methods for using such compositions, wherein the compositions are injected to a soft tissue site, preferably using a needle having a diameter of 20 gauge or smaller. The methods are particularly useful for deep tissue injection to locations near bone and cartilage for purposes such as sphincter repair, nasal repair, and the like.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a chart comparing the wet weight recovery at various concentrations of hydroxyapatite in Example A of the Experimental section.

Fig. 2 is a chart comparing the wet weight recovery at various concentrations of hydroxyapatite in Example B of the Experimental section.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Injectable implant compositions according to the present invention are prepared by comminution and size selection of a biocompatible ceramic starting material and incorporation of the resulting sized ceramic particles in a suitable fluid carrier. Optionally, a collagen material and other component(s) may be combined as part of the injectable implant compositions, and the compositions thus formed are useful for a variety of medical purposes, particularly soft tissue implantation and in particular deep tissue implantation to locations near bone, cartilage, and the like.

The sized ceramic particles will form the primary matrix material of the composition of the present invention. By "matrix material," it is meant that the material will persist within a host's tissue at the area of injection for a time sufficient to permit tissue repair or augmentation around and into the material. The fluid carrier will usually be viscous, more usually being a gel, in order to suspend and maximize the concentration of ceramic particles therein. Conveniently, the fluid carrier can be a viscous biocompatible organic polymer, such as polyethylene glycol, hyaluronic acid, poly (hydroxyethyl methacrylate), and the like.

Alternatively, the fluid carrier may comprise a hydrogel, particularly a collagen hydrogel (where the collagen may act both as a carrier and a co-matrix material). In any case, the fluid carrier together with the ceramic matrix particles will form a cohesive mass after injection to the desired tissue site. Overtime, the organic polymer and/or collagen will be resorbed, leaving the ceramic matrix as a supporting structure for the patient's own tissue.

Biocompatible ceramic matrix materials suitable for incorporation into the compositions of the invention may be derived from a variety of calcium phosphate mineral component materials. As used herein, "calcium

phosphate mineral" materials refers to thos materials composed of Ca^{+2} and phosphate ions, regardless of the microstructure, protonation status of the phosphate, or extent of hydration. Calcium phosphate mineral materials include a variety of forms, such as the commercially available forms of tricalcium phosphate, for example, Synthograft® tricalcium phosphate, or of hydroxyapatite such as Periograf®, Alveograf®, Interpore®, OrthoMatrix™ HA-1000™, or OrthoMatrix™ HA-500™ hydroxyapatite particulate preparations. The hydroxyapatite or tricalcium phosphate may also be prepared by known methods, such as those disclosed by Termine, et al. *Arch Biochem Biophys* (1970) 140:307-325, or by Hayashi et al. *Arch Orthop Trauma Surg* (1982. Supra). In any event, th mineral is generally and preferably of nonbiological origin and is supplied initially as a powder of having an average particle size typically in the range of 100-200 μm, with a maximum size of 1000μm or larger. While the mineral content of bone could be harvested and purified for this purpose, the use of commercially available calcium phosphate mineral will usually be more economical and preferable, both as a matter of cost and of quality.

The calcium phosphate starting materials will be subjected to conventional size reduction and selection processes to obtain a particle population having a size distribution in the range from 50 μm to 250 μm, preferably being from 100 μm to 200 μm. Particles larger than the upper ranges of these distributions will generally interfere with injectability of the compositions, while particles below the lower ranges of these distributions will be subject to phagocytosis when administered to soft tissue sites. Thus, this size range permits the successful use of the compositions of the present invention for soft tissue repair and augmentation using narrow gauge needle injection techniques. Size distribution can be measured microscopically using an image analyzer.

An exemplary method for size reduction and selection of calcium phosphate particles initially in the 100 μm to 1000 μm size range is set forth in the Experimental section hereinafter. Briefly, a calcium phosphate starting material, such as hydroxyapatite, is crushed into a fine powder having a very broad particle size distribution. The fine powder is wet screened in a device comprising a pair of vertically spaced-apart wire screens where the upper screen has a larger mesh size and the lower screen has a smaller mesh size. In particular, the upper screen is sized to prevent passage of particles larger than those in the desired particle size distribution while the lower screen is sized to permit passage of particles having a smaller particle size than the desired particle size distribution. Thus, the material retained on the upper surface of the lower screen will generally be within the desired particle size distribution.

The collagen component of the composition may be prepared or may be derived from a number of commercially available collagens. Numerous forms of collagen have been prepared and they differ in their physical properties as well as in their biocompatibility. The term, "collagen dispersion" is used herein to refer to a collagen preparation in aqueous medium in which the collagen particle size is not specified, i.e., the preparation may be a solution, suspension, or gel.

Native collagen consists mainly of a triple helical structure containing repeating triplet sequences composed of glycine linked to two additional amino acids, commonly proline and hydroxyproline. Native collagen contains regions at each end which do not have the triplet glycine sequence, and thus do not form helices. These regions are though to be responsible for the immunogenicity associated with most collagen preparations, and the immunogenicity can be mitigated by the removal of these regions to produce "atelopeptide"

collagen. This can be accomplished by digestion with proteolytic enzymes, such as trypsin and pepsin. The non-helical telopeptide regions are also responsible for natively occurring cross-linking, and atelopeptide collagen must be cross-linked artificially if cross-linking is desired.

Naturally occurring collagens have been subclassified into about ten types, depending on the amino acid sequence in the individual chains, the carbohydrate content, and the presence or absence of disulfide cross-links. The most common subtypes are Type I, which is present in skin, tendon, and bone, and which is made by fibroblasts; and Type III, which is found primarily in skin. Other types reside in specialized membranes or cartilage, or at cell surfaces. Types I and III contain similar numbers of amino acids in their helices and have a high degree of homology; however, Type III but not Type I, contains two adjacent cysteines at the C-terminal ends of the triple helix, which are capable of forming inter-chain cross-links.

Therefore, collagen preparations may differ from each other by virtue of their initial compositions, which is a function of their origin, or by virtue of their modes of preparation. Collagen derived from bone, for example, contains exclusively Type I collagen; while collagen derived from skin also contains Type III. Also, the process of preparation may or may not remove the telopeptides. Thus both unaltered and "atelopeptide" collagen are possible. Cross-linking may be effected deliberately or accidentally. Sterilization by γ-irradiation or by high heat may result in cross-linking without control of extent or nature and results in partial degradation of the triple helix; deliberate cross-linking may be carried out by a variety of means, including treatment with glutaraldehyde or polyethylene glycol. Differences arising from perhaps more subtle causes are perhaps the result of variations in the

details of the preparation procedure. For example, the collagen may be solubilized and reprecipitated, or may simply be finely divided and kept in suspension. When the solubilized material is reaggregated, the aggregation may be done in ways so as to form non-specifically bonded solids, or the collagen may be reconstituted into fibers which simulate the native form. Also, of course, the degree of purity may vary.

As used herein, "free from impurities" or "purified" as regards collagen preparations refers to those impurities which are normally associated with collagen in its native state. Thus, collagen prepared from calfskin is free from impurities when other components of calfskin have been removed; that from bone when other components of bone are eliminated.

"Reconstituted" collagen refers to collagen which has been disassembled into individual triple helical molecules, with or without their telopeptide extensions, brought into solution and then regrouped into "fibrillar" forms. In this form, the fibrils consist of long, thin collagen molecules staggered relative to one another by multiples of about one-fourth their length. This results in a banded structure which can be further aggregated into fibers.

Collagen which is "substantially free from cross-linking" refers to collagen which has had the telopeptides removed, and thus lacks the native capacity for cross-link formation. These preparations remain substantially cross-link free if not deliberately cross-linked by, for example, being treated with chemical crosslinking agents such as glutaraldehyde or subjected to treatment imposing a spurious form of linkage -- for example, treatments often used for sterilizing purpose, such as high temperature and γ-radiation.

The preferred collagen for incorporation into the composition of the present invention is a purified atelopeptide fibrillar reconstituted collagen. Non-

fibrillar collagen, however, may also be used. Non-fibrillar collagen may be degraded, e.g., by exposure to glycerol and may be maintained in non-fibrillar form at a neutral pH.

One suitable fibrillar collagen preparation is an atelopeptide collagen which is reconstituted into fibrillar form and supplied as a dispersion of 5-100 mg/ml, preferably around 50-70 mg/ml. Such dispersions as Zyderm® Collagen Implant (ZCI), which is commercially available in preparations containing 35 or 65 mg/ml collagen in saline, manufactured by Collagen Corporation, Palo Alto, California, are appropriate. For use in the compositions of the inventions, the ZCI or other collagen dispersions are used without lidocaine or other sedative drugs. As used herein, "ZCI" refers to the aqueous collagen dispersion, rather than to the collagen component per se.

The ceramic matrix particles and optionally the collagen component of the present invention will be combined in a suitable fluid carrier, typically a buffered aqueous media (pH 7.0 to 7.4). In the case of compositions which do not include a collagen component, the fluid carrier will typically consist of or further comprise a viscous organic polymer base material, such as polyethylene glycol, hyaluronic acid, poly (hydroxyethylene methacrylic acid) or the like. The organic polymer base does not act as a matrix material, i.e., it is not persistent and is quickly lost from a site of tissue administration leaving the ceramic particle matrix in place as the matrix. Instead, the organic polymer base acts to maintain the ceramic matrix particles in suspension and to form a cohesive mass at the injection site. Some organic polymers, such as polyethylene glycol, may also act as a lubricant. A preferred organic polymer is polyethylene glyol, particular having a molecular weight from 400 to 20,000.

The polyethylene glycol may be part of an aqueous solution or may be used without water.

The organic polymer base material is present in the ceramic implant compositions at a concentration from about 0.1% to 20% (weight basis), usually from about 0.5% to 10%, and preferably from about 0.5% to 5%.

In the case of the implant compositions which also include a collagen component, the addition of an organic polymer base is usually not necessary (although its presence is not intended to be excluded). The collagen in such compositions will typically be present at a concentration of at least 1% by weight, usually being present at from 1% to 20% by weight, and more usually being present at from 1% to 10% by weight. The persistence and texture of the implant composition can be controlled by adjusting the weight ratio of ceramic material to collagen, with higher amounts of ceramic corresponding to firmer, more persistent implants. Usually, the weight ratio will be in the range from about 1:19 to 1:1 (ceramic matrix: collagen), usually being in the range from about 1:9 to 1:1.5, and preferably being in the range from about 1:4 to 1:2.

It is important that the total solids content and viscosity of the compositions of the present invention be within a range which permits injection of the compositions through relatively narrow gauge needles, usually 20 gauge or higher, preferably 22 gauge or higher. The total solids content, including ceramics matrix particles, collagen, organic polymer, and the like, will usually be in the range from 60% (weight basis) to 4%, usually being in the range from 20% to 50%, and preferably being in the range from about 35% to 40%. The corresponding viscosities will usually be in the range from about 0.4 Pa/sec to 0.005 Pa/sec, usually being in the range from about 0.3 Pa/sec to 0.05 Pa/sec, and preferably being in the range from about 0.2 Pa/sec to 0.1 Pa/sec.

The compositions of the present invention may further include biocompatible fluid lubricants and/or viscosity modifiers, generally as described in U.S. Patent No. 4,803,075, the disclosure of which is incorporated herein by reference. Exemplary lubricant components include glycerol, glycogen, maltose, and the like. Organic polymer base materials, such as polyethylene glycol and hyaluronic acid as well as non-fibrillar collagen, preferably succinylated collagen, may also act as lubricants. Such lubricants generally act to enhance the intrudability into soft tissue and improve the injectability by modifying the viscosity of the compositions.

When used for hard tissue and bone implantation and repair, the compositions of the present invention may include additional components, such as osteogenic factors, as described generally in U.S. Patent Nos. 4,888,366; 4,863,732; and 5,001,169, the disclosures of which are incorporated herein by reference. The compositions may also include autologous bone marrow, as generally described in U.S. Patent No. 4,774,227, the disclosure of which is incorporated herein by reference.

In a preferred aspect of the present invention, biologically active substances (other than collagen), such as proteins and drugs, may be incorporated in the compositions to provide for controlled release of these active substances after injection of the compositions. Hydroxyapatite particles within the compositions of the present invention have a generally negative charge which can interact with positively charged proteins, drugs, and the like. In particular, the hydroxyapatite can interact with amino groups on a protein substance which is desired to be delivered to the host. Exemplary proteins would include tissue growth factors, such as TGF-β, and the like which would promote healing and tissue repair at the site of injection. Compositions of the present invention would be useful for delivering substances other than

growth promotants, and would therefore be useful for the controlled delivery of a wide variety of positively charged drug and proteins for purposes other than tissue repair and augmentation.

The components of the ceramic implant material of the present invention may be combined in any manner which provides for a homogeneous mixture. For example, components may be mixed homogeneously by repeated passage through pumps or repeated transfer between adjacent syringes having a small diameter interconnecting channel. A suitable syringe device providing the necessary mixing as described in U.S. Patent 4,743,229, the disclosure of which is incorporated herein by reference.

The injectable ceramic implant compositions of the present invention may be injected intradermally or subcutaneously into humans or other mammals to augment soft tissue, to repair tissue defects, to correct congenital anomalies, to correct cosmetic defects, and the like. The compositions of the present invention may also be injected into internal tissues, such as the tissues defining body sphincters to augment such tissues. See, in particular, copending applications serial no. 07/_____ (Attorney Docket No. 05921-10) and serial no. 07/_____ (Attorney Docket No. 05921-12), the disclosures of which are incorporated herein by reference. Specific uses of the implant compositions of the present invention are described in detail in the above patents and patent applications which have been incorporated herein by reference.

The injectable ceramic implant compositions of the present invention may also be used for repair or augmentation of hard tissues, such as bone, cartilage, connective tissues, and the like. The injectability of the compositions remains a particular benefit when they are being used in such hard tissue applications. Hard tissue and bone augmentation and repair are described generally in U.S. Patent Nos. 5,001,169; 4,863,732;

4,563,350, the disclosures of which are incorporated herein by reference.

The compositions of the present invention may be stored as a kit, where the separate components (i.e., the ceramic matrix, the fluid carrier, the collagen (if present), and other optional components are packaged in a ready-to-use syringe.

The following example is offered by way of illustration, not by way of limitation.

EXPERIMENTAL

Material Preparation

Sterile, non-pyrogenic hydroxyapatite (HA), having more rounded edges, of particle size 140-160 μm, was obtained from Lifecore Biomedical. Samples of the material were placed on a microscope slide, and the particle size distribution determined using image analysis.

The ceramic particles (average particle size 179 μm) were aseptically mixed with Zyderm®II Collagen Implant (ZCI) to concentrations of 10% and 30% ceramic, by weight, to form the collagen ceramic implants.

ZCI samples containing 10% ceramic or 30% ceramic were evaluated in subcutaneous tissue in rats. Approximately 0.25 cc samples were injected bilaterally in the suprascapular subcutis of Sprague-Dawley rats. At 14 and 28 days post-implantation, the implants were exposed and dissected free of the surrounding connective tissue. The total wet weight of the explant was determined, and each explant was evaluated histologically.

Histology Conclusion

Histology data reveal information relating to the implant's biocompatibility. The responses to all the test materials at 14 days were within the normal range of biocompatibility. However, calcification was seen in some of the implants. At day 28, all implants were reasonably biocompatible, except the ZCI containing 30%

HA, which had marginal biocompatibility. Many of the implants containing HA were showing signs of calcification; however, some calcification is typical in the rat subcutaneous model. None of the HA-containing implants showed granuloma formation, which is often seen in injectable particulate-containing compositions, such as Polytef® paste or Bioplastique™.

Wet Weight Persistence

Wet weight recovery is a measure of the implant's persistence. Wet weight recovery of the implant was constant in all formulations over 28 days. The recovery was slightly higher for the ZCI containing 30% HA. See Fig. 2.

Although the foregoing invention has been described in detail for purposes of clarity of understanding, it will be obvious that certain modifications may be practiced within the scope of the appended claims.

WHAT IS CLAIMED IS:

1. An injectable implant composition comprising a biocompatible ceramic matrix present in a pharmaceutically acceptable fluid carrier, wherein the ceramic matrix comprises particles having a size distribution in the range from 50 μm to 250 μm.

2. An injectable implant composition as in claim 1, wherein the ceramic matrix is composed of calcium phosphate mineral particles.

3. An injectable implant composition as in claim 2, wherein the calcium phosphate mineral particles are composed of a material selected from the group consisting of sintered hydroxyapatite and tricalcium phosphate.

4. An injectable implant composition as in claim 2, wherein the calcium phosphate mineral particles have enhanced surface porosity.

5. An injectable implant composition as in claim 1, wherein the ceramic matrix is present in the fluid carrier at a concentration from 0.75 gm/ml to 0.05 gm/ml.

6. An injectable implant composition as in claim 1, wherein the fluid carrier comprises a biocompatible organic polymer which will dissipate from a tissue injection site, leaving the mineral particles.

7. An injectable implant composition as in claim 6, wherein the organic polymer is polyethylene glycol.

8. An injectable implant composition as in claim 1, further comprising collagen, wherein the ceramic matrix and collagen are suspended in an aqueous fluid carrier.

9. An injectable implant composition as in claim 8, wherein the ceramic matrix and the fibrillar collagen are present at a weight ratio in the range from 1:19 to 1:1 ceramic matrix : collagen.

10. An injectable implant composition as in claim 1, further comprising a biocompatible fluid lubricant.

11. An injectable implant composition as in claim 10, wherein the biocompatible lubricant is glycerol or succinylated collagen.

12. An injectable implant composition as in claim 1, further comprising at least one positively charged biologically active substance.

13. An injectable implant composition as in claim 12, wherein the substance is a tissue growth factor.

14. A method for augmenting tissue in a living mammal, said method comprising subcutaneously injecting a composition including a ceramic matrix present in a pharmaceutically acceptable fluid carrier to a tissue site, wherein the ceramic matrix comprises particles having a size distribution in the range from 50 μm to 250 μm.

15. A method as in claim 14, wherein the tissue is soft tissue.

16. A method as in claim 14, wherein the tissue is hard tissue.

17. A method as in claim 14, wherein the composition is injected using a 20 gauge or finer needle.

18. A method as in claim 14, wherein the ceramic matrix is composed of calcium phosphate mineral particles.

19. A method as in claim 16, wherein the calcium phosphate mineral particles are composed of a material selected from the group consisting of sintered hydroxyapatite and tricalcium phosphate.

20. A method as in claim 14, wherein the ceramic matrix is present in the fluid carrier at a concentration from 0.75 gm/ml to 0.05 gm/ml.

21. A method as in claim 14, wherein the fluid carrier comprises a biocompatible organic polymer which will dissipate from a tissue injection site, leaving the mineral particles.

22. A method as in claim 21, wherein the organic polymer is a polyethylene glycol.

23. A method as in claim 14, further comprising collagen, wherein the ceramic matrix and collagen are suspended in an aqueous fluid carrier.

24. A method as in claim 23, wherein the ceramic matrix and the collagen are present at a weight ratio in the range from 1:19 to 1:1 ceramic matrix : collagen.

25. A method as in claim 14, wherein the composition further comprises a biocompatible fluid lubricant.

26. A method as in claim 25, wherein the biocompatible fluid lubricant is glycerol or succinylated collagen.

27. A method as in claim 14, wherein the composition further comprises at least one positively charged biologically active substance.

28. A method as in claim 25, wherein the substance is a tissue growth factor.

29. A method as in claim 14, wherein the tissue is bone and the composition further comprises a substance selected from the group consisting of osteogenic factor and bone marrow.

30. A method for preparing injectable implant compositions, said method comprising combining a ceramic matrix in a pharmaceutically acceptable fluid carrier, wherein the ceramic matrix comprises particles having a size distribution in the range from 50 μm to 250 μm.

31. A method as in claim 30, wherein the ceramic matrix particles are treated to enhance surface porosity prior for combination with the fluid carrier.

32. A method as in claim 30, wherein the ceramic matrix is composed of calcium phosphate mineral particles.

33. A method as in claim 30, wherein the calcium phosphate mineral particles are composed of a

material selected from the group consisting of sintered hydroxyapatite and tricalcium phosphate.

34. A method as in claim 30, wherein the ceramic matrix is combined in the fluid carrier at a concentration from 0.75 gm/ml to 0.05 gm/ml.

35. A method as in claim 30, wherein the fluid carrier comprises a biocompatible organic polymer which will dissipate from a tissue injection site, leaving the mineral particles.

36. A method as in claim 35, wherein the organic polymer is a polyethylene glycol.

37. A method as in claim 30, further comprising combining collagen, wherein the ceramic matrix and collagen are suspended in an aqueous fluid carrier.

38. A method as in claim 34, wherein the ceramic matrix and the collagen are combined at a weight ratio in the range from 1:19 to 1:1 ceramic matrix : collagen.

39. A method as in claim 30, further comprising combining the pharmaceutically acceptable fluid carrier with a biocompatible fluid lubricant.

40. A method as in claim 39, wherein the biocompatible fluid lubricant is glycerol of succinylated collagen.

41. A method as in claim 30, further comprising combining least one biologically active substance.

42. A method as in claim 41, wherein the substance is selected from the group consisting of tissue growth factors, osteogenic factors, and bone marrow.

43. A kit comprising:

a syringe loaded with a volume of a biocompatible ceramic matrix including particles having a size distribution in the range from 50 μm to 250 μm present in a fluid carrier.

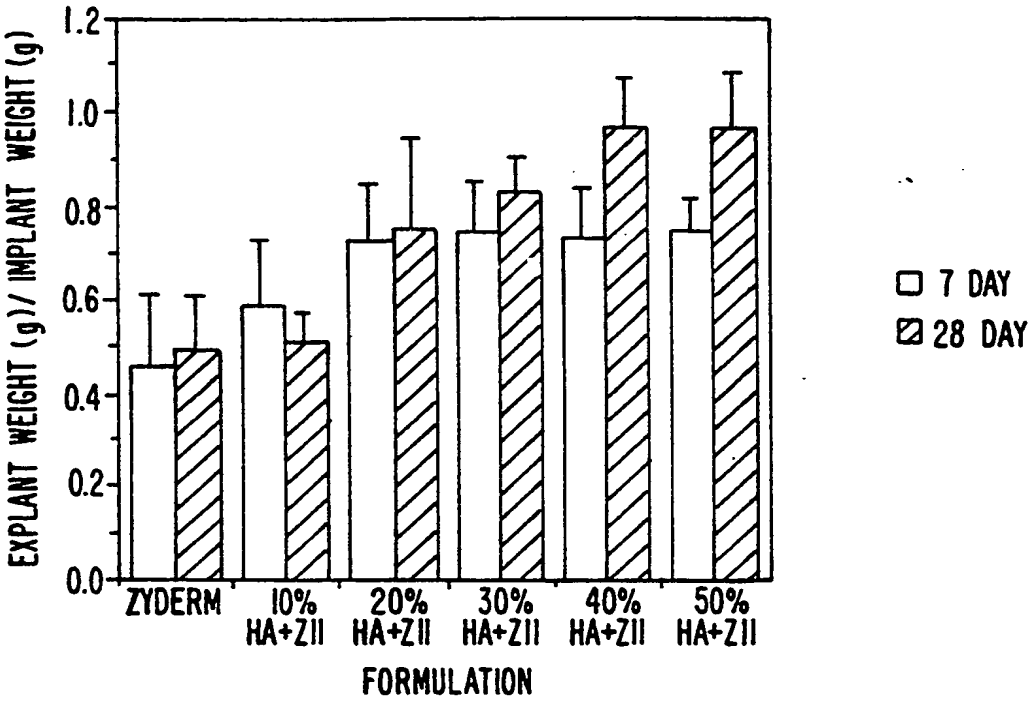
EXPLANT WEIGHT (g)/ IMPLANT WEIGHT (g)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
ZYDERM
10% HA+ZII
20% HA+ZII
30% HA+ZII
40% HA+ZII
50% HA+ZII
FORMULATION
7 DAY
28 DAY

FIG. 1.

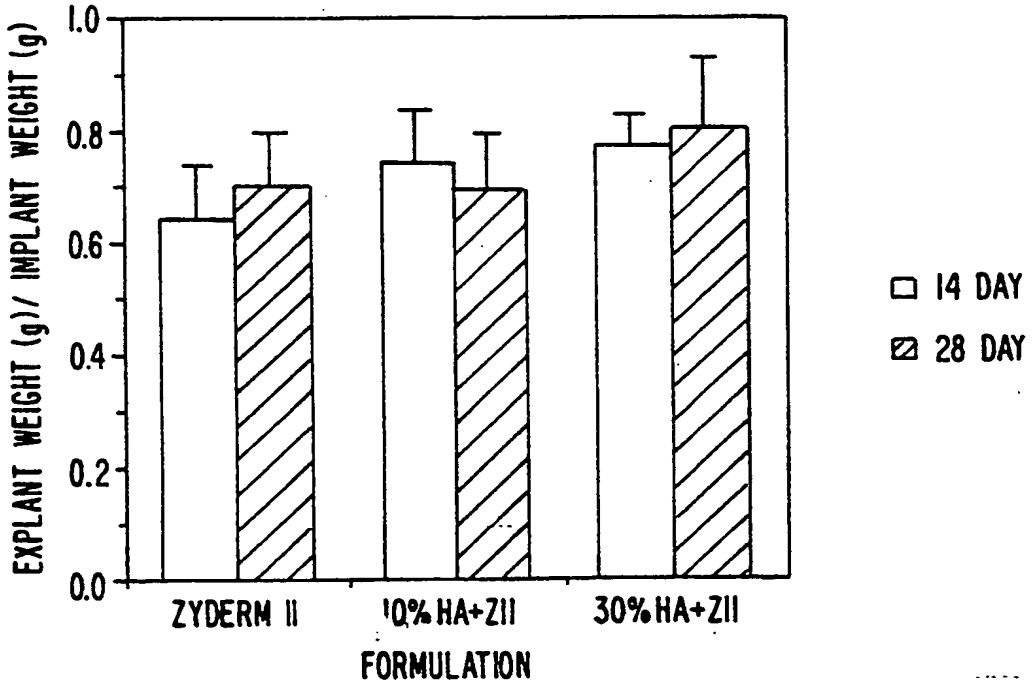
EXPLANT WEIGHT (g)/ IMPLANT WEIGHT (g)
1.0
0.8
0.6
0.4
0.2
0.0
ZYDERM II
10% HA+ZII
30% HA+ZII
FORMULATION
14 DAY
28 DAY

FIG. 2.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/01378

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61F 2/00
US CL :523/113, 115; 524/415, 417; 424/423, 425

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 523/113, 115; 524/415, 417; 424/423, 425

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US,A, 4,803,075 (WALLACE ET AL) 07 February 1989 See entire document.	1-43
Y	US,A, 4,684,673 (ADACHI) 04 August 1987 See entire document.	1-13 and 30-43
Y	US,A, 4,842,603 (DRAENERT) 27 June 1989 See entire document.	1-13 and 30-43
Y	US,A, 4,776,890 (CHU) 11 October 1988 See entire document.	1-13 and 30-43

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be part of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
30 MARCH 1993

Date of mailing of the international search report
29 APR 1993

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(54) Kits and compositions for the treatment and repair of defects or lesions in cartilage or bone.

(57) Kits and compositions are provided for the treatment and repair of defects in the cartilage or bone of humans and other animals as in full-thickness defects in joints. A matrix having pores large enough to allow cells to populate the matrix and to form blood vessels is used to fill the defect in bone. The matrix filling the bone defect contains an angiogenic factor and also contains an osteogenic factor in an appropriate delivery system. A matrix having pores sufficiently large to allow cartilage repair cells to populate the matrix is used to fill a defect in cartilage to induce cartilage formation. The matrix filling the defect in cartilage contains a proliferation agent and also contains a transforming factor in an appropriate delivery system. The matrix may also contain a chemotactic agent to attract cartilage repair cells. In a full-thickness defect, a membrane is used to separate the defect sites in bone and cartilage, which is sealed to the cartilage-bone-junction and which prevents blood vessels and associated cells from penetrating from one site to the other.

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This invention relates to pharmaceutical compositions for the treatment and repair of defects or lesions in cartilage or bone. More specifically, this invention relates to pharmaceutical compositions for treating defects or lesions (used interchangeably herein) in cartilage or bone and to compositions comprising a matrix containing one or more proliferating agents and a transforming factor to promote proliferation and transformation of cartilage repair cells to form new stable cartilage tissue and to compositions comprising a matrix containing an angiogenic factor to stimulate blood vessel formation and an osteogenic factor to stimulate formation of bone. The compositions of this invention are particularly useful in the treatment of full-thickness defects found in severe osteoarthritis, and in other diseases and traumas that produce cartilage or bone injury.

Joints are one of the common ways bones in the skeleton are connected. The ends of normal articulated bones are covered by articular cartilage tissue, which permits practically frictionless movement of the bones with respect to one another [L. Weiss, ed., Cell and Tissue Biology (Munchen: Urban and Schwarzenburg, 1988) p. 247].

Articular cartilage is characterized by a particular structural organization. It consists of specialized cells (chondrocytes) embedded in an intercellular material (often referred to in the literature as the "cartilage matrix") which is rich in proteoglycans, collagen fibrils of predominantly type II, other proteins, and water [Buckwalter et al., "Articular Cartilage: Injury and Repair," in Injury and Repair of the Musculoskeletal Soft Tissues (Park Ridge, Ill.: American Academy of Orthopaedic Surgeons Symposium, 1987) p. 465]. Cartilage tissue is neither innervated nor penetrated by the vascular or lymphatic systems. However, in the mature joint of adults, the underlying subchondral bone tissue, which forms a narrow, continuous plate between the bone tissue and the cartilage, is innervated and vascularized. Beneath this bone plate, the bone tissue forms trabeculae, containing the marrow. In immature joints, articular cartilage is underlined by only primary bone trabeculae. A portion of the meniscal tissue in joints also consists of cartilage whose make-up is similar to articular cartilage [Beaupre, A. et al., Clin. Orthop. Rel. Res., pp. 72-76 (1986)].

Two types of defects are recognized in articular surfaces, i.e., full-thickness defects and superficial defects. These defects differ not only in the extent of physical damage to the cartilage, but also in the nature of the repair response each type of lesion can elicit. .

Full-thickness defects of an articular surface include damage to the hyaline cartilage, the calcified cartilage layer and the subchondral bone tissue with its blood vessels and bone marrow. Full-thickness defects can cause severe pain since the bone plate contains sensory nerve endings. Such defects generally arise from severe trauma or during the late stages of degenerative joint disease, such as osteoarthritis. Full-thickness defects may, on occasion, lead to bleeding and the induction of a repair reaction from the subchondral bone [Buckwalter et al., "Articular Cartilage: Composition, Structure, Response to Injury, and Methods of Facilitating Repair," in Articular Cartilage and Knee Joint Function: Basic Science and Arthroscopy - (New York: Raven Press, 1990) pp. 19-56]. The repair tissue formed is vascularized fibrous type of cartilage with insufficient biomechanical properties, and does not persist on a long-term basis [Buckwalter et al. (1990), supra].

Superficial defects in the articular cartilage tissue are restricted to the cartilage tissue itself. Such defects are notorious because they do not heal and show no propensity for repair reactions.

Superficial defects may appear as fissures, divots, or clefts in the surface of the cartilage, or they may have a "crab-meat" appearance in the affected tissue. They contain no bleeding vessels (blood spots) such as are seen in full-thickness defects. Superficial defects may have no known cause, but often they are the result of mechanical derangements which lead to a wearing down of the cartilaginous tissue. Mechanical derangements may be caused by trauma to the joint, e.g., a displacement of torn meniscus tissue into the joint, meniscectomy, a laxation of the joint by a torn ligament, malalignment of joints, or bone fracture, or by hereditary diseases. Superficial defects are also characteristic of early stages of degenerative joint diseases, such as osteoarthritis. Since the cartilage tissue is not innervated [Ham's Histology - (9th ed.) (Philadelphia: J.B. Lippincott Co. 1987), pp. 266-272] or vascularized, superficial defects are not painful. However, although painless, superficial defects do not heal and often degenerate into full-thickness defects.

It is generally believed that because articular cartilage lacks a vasculature, damaged cartilage tissue does not receive sufficient or proper stimuli to elicit a repair response [Webber et al., "Intrinsic Repair Capabilities of Rabbit Meniscal Fibrocartilage: A Cell Culture Model", (30th Ann. Orthop. Res. Soc., Atlanta, Feb. 1984); Webber et al., J. Orthon. Res., 3, pp. 36-42 (1985)]. It is theorized that the chondrocytes in the cartilaginous tissue are normally not exposed to sufficient amounts of repair-stimulating agents such as growth factors and fibrin clots typically present in damaged vascularized tissue.

One approach that has been used to expose damaged cartilage tissue to repair stimuli involves

drilling or scraping through the cartilage into the subchondral bone to cause bleeding [Buckwalter et al. (1990), supra]. Unfortunately, the repair response of the tissue to such surgical trauma is usually comparable to that observed to take place naturally in full-thickness defects that cause bleeding, viz., formation of a fibrous type of cartilage which exhibits insufficient biomechanical properties and which does not persist on a long-term basis [Buckwalter et al. (1990), supra].

A variety of growth factors have been isolated and are now available for research and biomedical applications [see e.g., Rizzino, A., Dev. Biol., 130, pp. 411-422 (1988)]. Some of these growth factors, such as transforming growth factor beta (TGF-β), have been reported to promote formation of cartilage-specific molecules, such as type II collagen and cartilage-specific proteoglycans, in embryonic rat mesenchymal cells in vitro [e.g., Seyedin et al., Proc. Natl. Acad. Sci. USA, 82, pp. 2267-71 (1985); Seyedin et al., J. Biol. Chem., 261, pp. 5693-95 (1986); Seyedin et al., J. Biol. Chem., 262, pp. 1946-1949 (1987)].

Furthermore, a number of protein factors have been identified that apparently stimulate formation of bone. Such osteogenic factors include bone morphogenetic proteins, osteogenin, bone osteogenic protein (BOP), TGF-βs, and recombinant bone inducing proteins.

Millions of patients have been diagnosed as having osteoarthritis, i.e., as having degenerating defects or lesions in their articular cartilage. Nevertheless, despite claims of various methods to elicit a repair response in damaged cartilage, none of these treatments has received substantial application [Buckwalter et al. (1990), supra; Knutson et al., J. Bone and Joint Surg., 68-B, p. 795 (1986); Knutson et al., J. Bone and Joint Surg., 67-B, p. 47 (1985); Knutson et al., Clin. Orthop., 191, p. 202 (1984); Marquet, Clin. Orthop., 146, p. 102 (1980)]. And such treatments have generally provided only temporary relief. Systemic use of "chondroprotective agents" has also been purported to arrest the progression of osteoarthritis and to induce relief of pain. However, such agents have not been shown to promote repair of lesions or defects in cartilage tissue.

To date, treatment of patients suffering from osteoarthritis has been directed largely to symptomatic relief through the use of analgesics and anti-inflammatory agents. Without a treatment that will elicit repair of superficial defects in articular cartilage, the cartilage frequently wears down to the subchondral bone plate. At this phase of the disease, i.e., severe osteoarthritis, the unremitting nature of the pain and the significant compromise of function often dictates that the entire joint be excised and replaced with an artificial joint of metal and/or plastic. Some one-half million procedures comprising joint resection and replacement with an artificial joint are currently performed on knees and hips each year. [See e.g., Graves, E. J., "1988 Summary; National Hospital Discharge Survey", Advanced Data From Vital and Health Statistics, 185, pp. 1-12 (June 19, 1990)].

There is, therefore, a need for a reliable treatment for cartilage in superficial cartilage defects, e.g., as found in the early stages of osteoarthritis. There is also a needs for treatment of cartilage or bone defects as found in the lesions of severe osteoarthritis and for the treatment of other bone defects.

The present invention solves the problems referred to above by providing effective therapeutic kits and compositions to induce the repair of lesions in cartilage or bone of humans and other animals. Use of the kits and compositions of this invention also promote the healing of traumatic lesions and forms of osteoarthritis which would otherwise lead to loss of effective joint function leading to probable resection and replacement of the joint.

In general outline, the kits of this invention for repairing full-thickness defects in joints a matrix that will be incorporated into the animal tissue and is generally biodegradable which may be used for filling the defect in the bone portion of a full-thickness defect up to the level of the bone-cartilage interface. The kit also comprises a membrane, which is impermeable to cells and may be used to cover the matrix filling the bone defect. The membrane is sealed to the edges of the defect at the cartilage-bone junction, e.g., by sealing to the cartilage by thermal bonding using a thermal knife or laser. The kit further comprises a matrix which contains a chondrogenic composition, and which will be incorporated into the animal tissue and is generally biodegradable and may be used to fill the remaining. cartilage portion of the defect to the top of the cartilage surface. The matrix containing angiogenic and osteogenic factors may also be applied to any bone defect to promote repair. The compositions of this invention for repairing bone defects that do not involve cartilage, are such that the bone defect is filled with a composition comprising a matrix containing angiogenic factor(s) and osteogenic factor(s). The osteogenic factor(s) is packaged in an appropriate delivery system.

The kits and compositions for the treatment of full-thickness defects can be used during arthroscopic, open surgical or percutaneous procedures. Certain kits of this invention may be used such that after identification of the defect, (1) a composition comprising a matrix containing an angiogenic factor and an osteogenic factor packaged in an appropriate delivery system, e.g., liposomes,

is used for filling the bone portion of the defect; (2) a membrane, preferably a biodegradable membrane, which prevents cells from migrating from the bone defect side to the cartilage defect side, is used by placing it over the matrix in the bone defect and sealing the membrane to the edges of the defect at the cartilage-bone junction; and (3) a composition comprising a matrix, preferably biodegradable, and containing a proliferation agent and a transforming factor which is packaged in an appropriate delivery system is used for filling the cartilage portion of the defect.

In this last step, the matrix is bonded to the surface of the cartilage portion of the full-thickness defect, for example, by using an adhesion-promoting factor, such as transglutaminase.

In order that the invention may be more fully understood, the following detailed description is provided. In the description the following terms are used. --

Angiogenic Factor -- as used herein, refers to any peptide, polypeptide, protein or any other compound or composition which induces or stimulates the formation of blood vessels and associated cells (such as endothelial, perivascular, mesenchymal and smooth muscle cells) and blood vessel-associated basement membranes. In vivo and in vitro assays for angiogenic factors are well-known in the art [e.g., Gimbrone, M. A., et al., J. Natl. Cancer Inst., 52, pp. 413-419 (1974); Klagsbrun, M. et al., Cancer Res., 36, pp. 110-113 (1976); Gross et al., Proc. Natl. Acad. Sci. (USA), 80, pp. 2623-2627 (1983); Gospodarowicz et al., Proc. Natl. Acad. Sci. (USA), 73, pp. 4120-4124 (1976); Folkman et al., Proc. Natl. Acad. Sci. (USA), 76, pp. 5217-5221 (1979); Zetter, B. R., Nature (London), 285, pp. 41-43 (1980); Azizkhan, R. G. et al., J. Exp. Med., 152, pp. 931-944 (1980)].

Arthroscopy -- as used herein, refers to the use of an arthroscope to examine or perform surgery on a joint.

Bone -- as used herein, refers to a calcified connective tissue primarily comprising a network of deposited calcium and phosphate in the form of hydroxyapatite, collagen (predominantly type I collagen) and bone cells, such as osteoblasts and osteoclasts.

Bone Repair Cell -- as used herein, refers to a cell which, when exposed to appropriate stimuli, will differentiate and be transformed into a bone cell, such as an osteoblast or an osteocyte, which forms bone. Bone repair cells include perivascular cells, mesenchymal cells, fibroblasts, fibroblast-like cells and dedifferentiated chondrocytes.

Cartilage -- as used herein, refers to a type of connective tissue that contains chondrocytes embedded in an intercellular material (often referred to as the "cartilage matrix") comprising fibrils of collagen (predominantly type II collagen along with other minor types, e.g., types IX and XI), various proteoglycans (e.g., chondroitinsulfate-, keratansulfate-, and dermatansulfate proteoglycans), other proteins, and water. Cartilage as used herein includes articular and meniscal cartilage. Articular cartilage covers the surfaces of the portions of bones in joints and allows movement in joints without direct bone-to-bone contact, and thereby prevents wearing down and damage to apposing bone surfaces. Most normal healthy articular cartilage is also described as "hyaline", i.e., having a characteristic frosted glass appearance. Meniscal cartilage is usually found in joints which are exposed to concussion as well as movement. Such locations of meniscal cartilage include the temporo-mandibular, sterno-clavicular, acromio-clavicular, wrist and knee joints [Gray's Anatomy - (New York: Bounty Books, 1977)].

Cartilage Repair Cell -- as used herein, refers to a cell which, when exposed to appropriate stimuli, will differentiate and be transformed into a chondrocyte. Cartilage repair cells include mesenchymal cells, fibroblasts, fibroblast-like cells, macrophages and dedifferentiated chondrocytes.

Cell Adhesion Promoting Factor -- as used herein, refers to any compound or composition, including fibronectin and other peptides as small as tetrapeptides which comprise the tripeptide Arg-Gly-Asp, which mediates the adhesion of cells to extracellular material [Ruoslathi et al., Cell, 44, pp. 517-518 (1986)].

Chemotactic Agent -- as used herein, refers to any compound or composition, including peptides, proteins, glycoproteins and glycosaminoglycan chains, which is capable of attracting cells in standard in vitro chemotactic assays [e.g., Wahl et al., Proc. Natl. Acad. Sci. USA, 84, pp 5788-92 (1987); Postlewaite et al., J. Exp. Med., 165, pp. 251-56 (1987); Moore et al., Int. J. Tiss. Reac., XI, pp. 301-07 (1989)].

Chondrocytes -- as used herein, refers to cells which are capable of producing components of cartilage tissue, e.g., type II cartilaginous fibrils and fibers and proteoglycans.

Fibroblast growth factor (FGF) -- any member of the family of FGF polypeptides [Gimenez-Gallego et al., Biochem. Biophys. Res. Commun., 135, pp. 541-548 (1986); Thomas et al., Trends Biochem. Sci., 11, pp. 81-84 (1986)] or derivatives thereof, obtained from natural, synthetic or recombinant sources, which exhibits the ability to stimulate DNA synthesis and cell division in vitro [for assays see, e.g., Gimenez-Gallego et al., 1986, supra; Canalis et al., J. Clin. Invest., 81, pp. 1572-1577 (1988)] of a variety of cells, including primary fibroblasts, chondrocytes, vascular and corneal endothelial cells, osteoblasts, myoblasts, smooth

muscle and glial cells [Thomas et al., 1986, supra]. FGFs may be classified as acidic (aFGF) or basic (bFGF) FGF, depending on their isoelectric points (pI).

Matrix -- as used herein, refers to a porous composite, solid or semi-solid substance having pores or spaces sufficiently large to allow cells to populate the matrix. The term matrix includes matrix-forming materials, i.e., materials which can form matrices within a defect site in cartilage or bone. Matrix-forming materials may require addition of a polymerizing agent to form a matrix, such as adding thrombin to a solution containing fibrinogen to form a fibrin matrix. Other matrix materials include collagen, combinations of collagen and fibrin, agarose (e.g., Sepharose®), and gelatin. Calcium phosphate may be used alone or in combination with other matrix materials in treating defects in bones.

Membrane -- as used herein, refers to any material which can be placed between the bone defect portion and the cartilage defect portion of a full thickness defect and which prevents cell migration and blood vessel infiltration from the bone defect portion into the cartilage defect portion of the full thickness defect. The membranes used in the methods and compositions of this invention for the repair of full thickness defects are preferably biodegradable.

Osteogenic Factor -- as used herein, refers to any peptide, polypeptide, protein or any other compound or composition which induces or stimulates the formation of bone. The osteogenic factor induces differentiation of bone repair cells into bone cells, such as osteoblasts or osteocytes. This process may be reached via an intermediary state of cartilage tissue. The bone tissue formed from bone cells will contain bone specific substances such as type I collagen fibrils, hydroxyapatite mineral and various glycoproteins and small amounts of bone proteoglycans.

Proliferation (mitogenic) Agent -- as used herein, refers to any compound or composition, including peptides, proteins, and glycoproteins, which is capable of stimulating proliferation of cells in vitro. In vitro assays to determine the proliferation (mitogenic) activity of peptides, polypeptides and other compounds are well-known in the art [see, e.g., Canalis et al., J. Clin. Invest., pp. 1572-77 (1988); Gimenez-Gallego et al., Biochem. Biophys. Res. Commun., 135, pp. 541-548 (1986); Rizzino, "Soft Agar Growth Assays for Transforming Growth Factors and Mitogenic Peptides", in Methods Enzymol., 146A (New York: Academic Press, 1987), pp. 341-52; Dickson et al., "Assay of Mitogen-Induced Effects on Cellular Incorporation of Precursors for Scavengers, de Novo, and Net DNA Synthesis", in Methods Enzymol., 146A (New York: Academic Press, 1987), pp. 329-40]. One standard method to determine the proliferation (mitogenic) activity of a compound or composition is to assay it in vitro for its ability to induce anchorage-independent growth of nontransformed cells in soft agar [e.g., Rizzino, 1987, supra]. Other mitogenic activity assay systems are also known [e.g., Gimenez-Gallego et al., 1986, supra; Canalis et al., 1988, supra; Dickson et al., 1987, supra]. Mitogenic effects of agents are frequently very concentration-dependent, and their effects can be reversed at lower or higher concentrations than the optimal concentration range for mitogenic effectiveness.

Transforming Factor -- as used herein, refers to any peptide, polypeptide, protein, or any other compound or composition which induces differentiation of a cartilage repair cell into a chondrocyte. The ability of the compound or composition to induce or stimulate production of cartilage-specific proteoglycans and type II collagen by cells can be determined by in vitro assays known in the art [Seyedin et al., Proc. Natl. Acad. Sci. USA, 82, pp. 2267-71 (1985); Seyedin et al., Path. Immunol. Res., 7, pp. 38-42 (1987)].

Transforming Growth Factor Beta (TGF-β) --any member of the family of TGF-β polypeptides [Derynck, R. et al., Nature, 316, pp. 701-705 (1985); Roberts et al., "The transforming growth factor-β's", In Peptide growth factors and their receptors I (Berlin: Springer Verlag, 1990), p. 419)] or derivatives thereof, obtained from natural, synthetic or recombinant sources, which exhibits the characteristic TGF-β ability to stimulate normal rat kidney (NRK) cells to grow and form colonies in a soft agar assay [Roberts et al., "Purification of Type β Transforming Growth Factors From Nonneoplastic Tissues", in Methods for Preparation of Media, Supplements, and Substrata for Serum-Free Animal Cell Culture (New York: Alan R. Liss, Inc., 1984)] and which is capable of inducing transformation of cartilage repair cells into chondrocytes as evidenced by the ability to induce or stimulate production of cartilage-specific proteoglycans and type II collagen by cells in vitro [Seyedin et al., 1985, supra].

This invention relates to compositions and kits for treating defects or lesions in cartilage or bone. The compositions of this invention comprise matrices having pores sufficiently large to allow cells to populate the matrices.

For use in the repair of cartilage as in superficial defects or the cartilage layer in a full-thickness defect, the matrix will also contain a proliferation agent to stimulate the proliferation of cartilage repair cells in the matrix. Preferably, the proliferation agent also serves as a chemotactic agent to attract cartilage repair cells to the matrix. Alternatively, the matrix may contain a chemotactic agent in addition to the proliferation agent. In one preferred embodi-

ment of this invention, the matrix also contains an appropriate concentration of a transforming factor, the transforming factor being contained within or in association with a delivery system which effects release of the transforming factor at the appropriate time to transform the proliferated cartilage repair cells in the matrix into chondrocytes which produce. stable cartilage tissue. The matrix may also contain a cell adhesion promoting factor.

Matrix materials useful in the methods and compositions of this invention for filling or otherwise dressing the cartilage or bone defects include fibrinogen (activated with thrombin to form fibrin in the defect or lesion), collagen, agarose, gelatin and any other biodegradable material which forms a matrix with pores sufficiently large to allow cartilage or bone repair cells to populate and proliferate within the matrix and which can be degraded and replaced with cartilage or bone during the repair process. In some instances, calcium phosphate containing compounds may be used alone or in combination with other biodegradable matrix materials in treating bone defects.

The matrices useful in the compositions and kits of this invention may be preformed or may be formed in situ, for example. by polymerizing compounds and compositions such as fibrinogen to form a fibrin matrix. Matrices that may be preformed include collagen (e.g., collagen sponges and collagen fleece), chemically modified collagen, gelatin beads or sponges, a gel-forming substance such as agarose, and any other gel-forming or composite substance that is composed of a matrix material that will fill the defect and allow cartilage or bone repair cells to populate the matrix, or mixtures of the above.

In one embodiment of this invention, the matrix is formed using a solution of fibrinogen, to which is added thrombin to initiate polymerization shortly before use. A fibrinogen concentration of 0.5-5 mg/ml of an aqueous buffer solution may be used. Preferably, a fibrinogen solution of 1 mg/ml of an aqueous buffer solution is used. Polymerization of this fibrinogen solution in the defect area yields a matrix with a pore size sufficiently large (e.g., approximately 50-200 μm) so that cartilage or bone repair cells are free to populate the matrix and proliferate in order to fill the volume of the defect that the matrix occupies. Preferably, a sufficient amount of thrombin is added to the fibrinogen solution shortly before application in order to allow enough time for the surgeon to deposit the material in the defect area prior to completion of polymerization. Typically, the thrombin concentration should be such that polymerization is achieved within a few to several (2-4) minutes since exposure of cartilage to air for lengthy periods of time has been shown to cause damage [Mitchell et al., J. Bone Joint Surg., 71A, pp. 89-95 (1989)]. Excessive amounts of thrombin should not be used since thrombin has the ability to cleave growth factor molecules and inactivate them. Thrombin solutions of 10-500 units per ml, and preferably 100 units per ml, of an aqueous buffer solution may be prepared for addition to the fibrinogen solution. In a preferred embodiment of this invention, approximately 20 μl of thrombin (100 U/ml) are mixed with each ml of a fibrinogen solution (1 mg/ml) approximately 200 seconds before filling the defect. Polymerization will occur more slowly if a lower concentration of thrombin is added. It will be appreciated that the amount of thrombin solution needed to achieve fibrin polymerization within 2-4 minutes can be given only approximately, since it depends upon the environmental temperature, the temperature of the thrombin solution, the temperature of the fibrinogen solution, etc. The polymerization of the thrombin-activated matrix solution filling the defect is easily monitored by observing the thrombin-induced polymerization of an external sample of the fibrinogen solution. Preferably, in the compositions and methods of this invention, fibrin matrices are formed from autologous fibrinogen molecules, i.e., fibrinogen molecules derived from the blood of the same mammalian species as the species to be treated. Non-immunogenic fibrinogen from other species may also be used.

Matrices comprising fibrin and collagen may also be used in the compositions and kits of this invention. In a preferred embodiment of this invention, collagenous matrices are used.

When collagen is used as a matrix material, sufficiently viscous solutions can be made, e.g., using Collagen-Vliess® ("fleece"), Spongostan®, or gelatine-blood-mixtures, and there is no need for a polymerizing agent. Collagen matrices may also be used with a fibrinogen solution activated with a polymerizing agent so that a combined matrix results.

Polymerizing agents may also be unnecessary when other biodegradable compounds are used to form the matrix. For example, Sepharose® solutions may be chosen that will be liquid matrix solutions at 39-42 °C and become solid (i.e., gel-like) at 35-38 °C. The Sepharose should also be at concentrations such that the gel filling the defect has a mesh size to allow bone or cartilage repair cells to freely populate the matrix and defect area.

In the compositions of this invention used in cartilage repair, one or more proliferation (mitogenic) agents may be added to the matrix solution. The proliferation agent or agents should be present in an appropriate concentration range to have a proliferative effect on cartilage repair cells in the matrix filling the defect. Preferably, the same agent should also have a chemotactic effect on the

cells (as in the case of TGF-β); however, a factor having exclusively a proliferative effect may be used. Alternatively, to produce chemotactic cell immigration, followed by induction of cell proliferation, two different agents may be used, each one having just one of those specific effects (either chemotactic or proliferative).

Proliferation (mitogenic) agents useful in the compositions and kits of this invention for stimulating the proliferation of cartilage repair cells include transforming growth factors ("TGFs") such as TGF-αs and TGF-βs; insulin-like growth factor ("IGF I"); acidic or basic fibroblast growth factors ("FGFs"); platelet-derived growth factor ("PDGF"); epidermal growth factor ("EGF"); and hemopoietic growth factors, such as interleukin 3 ("IL-3") [Rizzino, 1987, supra; Canalis et al., supra, 1988; Growth factors in biology and medicine, Ciba Foundation Symposium, 116 (New York: John Wiley & Sons, 1985); Baserga, R., ed., Cell growth and division (Oxford: IRL Press, 1985); Sporn, M.A. and Roberts, A.B., eds., Peptide growth factors and their receptors, Vols. I and II (Berlin: Springer-Verlag, 1990)]. However, these particular examples are not limiting. Any compound or composition which is capable of stimulating the proliferation of cells as demonstrated by an in vitro assay for cell proliferation is useful as a proliferation agent in this invention. Such assays are known in the art [e.g., Canalis et al., 1988, supra; Gimenez-Gallego et al., 1986, supra; Dickson et al., 1987, supra; Rizzino, 1987, supra].

Chemotactic agents useful in the compositions and kits of this invention for attracting cartilage repair cells to the cartilage defect include, for example, TGF-βs, FGFs (acid or basic), PDGF, tumor necrosis factors (e.g., TNF-α, TNF-β) and proteoglycan degradation products, such as glycosaminoglycan chains [Roberts et al. (1990), supra; Growth factors in biology and medicine, Ciba Foundation Symposium, 116 (New York, John Wiley & Sons, 1985); R. Baserga, ed., Cell growth and division (Oxford: IRL Press, 1985)]. Assays to determine the chemotactic ability of polypeptides and other compounds are known in the art [e.g., Postlewaite et al., 1987, supra; Wahl et al., 1987, supra; Moore et al., 1989, supra].

In a preferred embodiment of this invention, the matrix used in cartilage repair contains TGF-β as the proliferation agent and as the chemotactic agent. In particular, TGF-βI or TGF-βII may be used as the proliferation and chemotactic agent. Other TGF-β forms (e.g., TGF-βIII, TGF-βIV, TGF-βV, etc.) or polypeptides having TGF-β activity [see Roberts, 1990, supra] may also be useful for this purpose, as well as other forms of this substance to be detected in the future, and other growth factors. For use as the proliferation agent and chemotactic agent, TGF-β molecules are dissolved or suspended in the matrix at a concentration of preferably 2-50 ng/ml of matrix solution, and most preferably, 2-10 ng/ml of matrix solution. It will be appreciated that the preferred concentration of TGF-β that will stimulate proliferation of cartilage repair cells may vary with the particular animal to be treated.

A transforming factor or factors may also be present in the matrix solution used in cartilage repair so that after cartilage repair cells have populated the matrix, the transforming factor will be released into the defect site in a concentration sufficient to promote differentiation (i.e., transformation) of the cartilage repair cells into chondrocytes which form new stable cartilage tissue. Proper timing of the release of the transforming factor is particularly important if the transforming factor can inhibit or interfere with the effectiveness of the proliferation agent [see Roberts et al. (1990), supra].

Transforming factors useful in the compositions and kits of this invention to promote cartilage repair include any peptide, polypeptide, protein or any other compound or composition which induces differentiation of cartilage repair cells into chondrocytes which produce cartilage-specific proteoglycans and type II collagen. The ability of a compound or composition to induce or stimulate production of cartilage-specific proteoglycans and type II collagen in cells can be determined using assays known in the art [e.g., Seyedin et al., 1985, supra; Seyedin et al., 1987, supra]. The transforming factors useful in the compositions and kits of this invention include, for example, TGF-βs, TGF-αs and FGFs (acid or basic). These transforming factors may be used singly or in combination. In addition, TGF-β may be used in combination with EGF.

The properly timed release of the transforming factor may be achieved by packaging the transforming factor in or with and appropriate delivery system. Delivery systems useful in the compositions and kits of this invention include liposomes, bioerodible polymers, carbohydrate-based corpuscles, water-oil emulsions, fibers such as collagen which are chemically linked to heparin sulfate proteoglycans or other such molecules to which transforming factors bind spontaneously, and osmotic pumps. Delivery systems such as liposomes, bioerodible polymers, fibers with bound transforming factors and carbohydrate-based corpuscles containing the transforming agent may be mixed with the matrix solution used to fill the defect. These systems are known and available in the art [see P. Johnson and J. G. Lloyd-Jones, eds., Drug Delivery Systems (Chichester, England: Ellis Horwood Ltd., 1987)]. Liposomes may be prepared

according to the procedure of Kim et al., Biochem. Biophys. Acta, 728, pp. 339-348 (1983). Other liposome preparation procedures may also be used. Additional factors for stimulating chondrocytes to synthesize the cartilage tissue components may be included with the transforming factor in the delivery system.

In a preferred embodiment of this invention, the matrix used in cartilage repair contains TGF-β as the proliferation and chemotactic agent, and contains TGF-β packaged in a delivery system as the transforming factor. In particular, TGF-βI or TGF-βII may be used as the proliferation and chemotactic agent and as the transforming factor. Other TGF-β forms (e.g., TGF-βIII, TGF-βIV, TGF-βV, etc.) or polypeptides having TGF-β activity (see Roberts, 1990, supra) may also be useful for this purpose, as well as other forms of this substance to be detected in the future, and other growth factors.

In a preferred embodiment for cartilage repair, a TGF-β concentration of preferably 2-50 ng/ml of matrix solution, and most preferably, 2-10 ng/ml of matrix solution, is used as a proliferation agent and as a chemotactic agent. A substantially higher concentration of TGF-β is also present in a subsequently releasable form in the matrix composition as a transforming factor. Preferably, the subsequent concentration of TGF-β is greater than 200 ng/ml of matrix and, most preferably, is greater than 500 ng ml of matrix. It will be appreciated that the preferred concentration of TGF-β to induce differentiation of cartilage repair cells may vary with the particular animal to be treated.

It is necessary to stagger the exposure of the cartilage repair cells to the two concentration ranges of TGF-β, since TGF-β at relatively high concentrations (e.g., greater than 200 ng/ml of matrix solution) may not only transform cartilage repair cells into chondrocytes, but also will inhibit chemotactic attraction of cartilage repair cells; whereas at relatively low concentrations (e.g., 2-10 ng/ml), TGF-β attracts cartilage repair cells and stimulates their proliferation, but will not induce transformation of cartilage repair cells into chondrocytes which produce cartilage tissue.

In a preferred embodiment of this invention, in order to obtain the sequence of chemotaxis and proliferation, followed by transformation, TGF-β is present both in a free, unencapsulated form and in an encapsulated, or otherwise sequestered, form in the matrix. Preferably, for the purpose of attracting and inducing proliferation of cartilage repair cells in the matrix and defect area, TGF-β molecules are dissolved or suspended in the matrix at a concentration of 2-10 ng/ml of matrix solution. To promote transformation of cartilage repair cells in the matrix into chondrocytes, TGF-β molecules are also present in the matrix sequestered in multivesicular liposomes according to the method of Kim et al., 1983, supra, at a concentration of greater than 200 ng/ml of matrix solution, and preferably at a concentration of greater than 500 ng/ml. The TGF-β-loaded liposomes are disrupted when the attracted cartilage repair cells have populated the matrix and have started to degrade the matrix. During the degradation of the matrix, the cartilage repair cells ingest and/or degrade the liposomes, resulting in the release of TGF-β at concentrations sufficient to induce the transformation of cartilage repair cells into chondrocytes.

The required two-stage delivery of chemotactic and proliferating versus transforming concentrations of TGF-β may also be achieved by combining transforming concentrations of TGF-β with a bioerodible polymer. Alternatively, a pump, and preferably an implanted osmotic pump, may be used to control the concentration of TGF-β in the defect and matrix. In this embodiment of the invention, the pump controls the concentration of TGF-β in the matrix, i.e., the pump may release TGF-β at an initial chemotactic and proliferation stimulating concentration and at a subsequent transforming concentration. Preferably, the transforming concentration of TGF-β is delivered by the pump approximately 1 to 2 weeks post-operatively. Delivery of the transforming factor into the defect volume is preferably localized to the matrix in the defect site.

The proliferation agents and, when used, the transforming factors in the compositions of this invention are applied in the defect site within the matrix. Their presence is thus restricted to a very localized site. This is done to avoid their free injection or infusion into a joint space. Such free infusion may produce the adverse effect of stimulating the cells of the synovial membrane to produce joint effusion.

In the compositions of this invention used in bone repair, one or more angiogenic factors is added to the matrix solution to stimulate the formation and ingrowth of blood vessels and associated cells (e.g., endothelial, perivascular, mesenchymal and smooth muscle cells) and of basement membranes in the area of the bone defect. Angiogenic factors useful in the compositions and kits of this invention for stimulating vascularization throughout the deposited matrix in the area of the bone defect include bFGF, TGF-β, PDGF, TNF-α, angiogenin or angiotropin. Heparin sulfate has been found to enhance the angiogenic activity of bFGF. In a preferred embodiment of this invention, bFGF and heparin sulfate are dissolved, suspended or bound in a matrix at a concentration of approximately 10 ng/ml of matrix solution. The preferred concentrations for other angiogenic factors are: 5 ng/ml of matrix solution for TGF-β, 10 ng/ml of matrix solution for TNF-α, and 10 ng/ml of matrix solution for

PDGF. However, bFGF in combination with heparin sulfate is the most preferred angiogenic factor among the above named angiogenic factors.

An osteogenic factor is also present in the matrix solution used in bone repair so that after blood vessels and associated cells have populated the matrix, the osteogenic factor is released into the bone defect site as the matrix is degraded in a concentration sufficient to promote a process leading to the eventual development of osteoblasts and osteocytes. The osteogenic factor is sequestered or packaged in an appropriate delivery system within the matrix and is released as the matrix is degraded. The delivery systems used in the cartilage repair compositions are useful in the bone repair compositions of this invention, e.g., liposomes or carbohydrate-based corpuscles (see supra). In one embodiment of this invention, the matrix used in bone repair contains TGF-β packaged in a delivery system as the osteogenic factor, at a concentration of 100 ng/ml of matrix solution. Lower and higher concentrations of TGF-β may be used.

Osteogenic factors useful in the bone repair compositions of this invention include any peptide, polypeptide, protein or any other compound or composition which induces differentiation of bone repair cells into bone cells, such as osteoblasts and osteocytes, which produce bone tissue. The osteogenic factors useful in this invention include proteins such as TGF-β [Sampath, T. R. et al., J. Biol. Chem., 265(22), pp. 13198-13205 (1990)], osteogenin [Luyten, F. P. et al., J. Biol. Chem., 264(15), pp. 13377-80 (1989)], bone morphogenic protein (BMP) [Wang, E. et al., Proc. Natl. Acad. Sci. USA, 87, pp. 2220-24 (1990)], and TGF-β combined with epidermal growth factor (EGF).

The differentiation of mesenchymal cells induced by an osteogenic factor may include the formation of intermediary tissues such as fibrous, hyaline and calcified cartilage; and endochondral ossification, which leads to the formation of woven bone tissue, which will become remodelled and transformed into mature lamellar bone tissue. In some instances, bone may be formed directly from mesenchymal cells without the appearance of an intermediary tissue. Within the matrix, the process of bone tissue formation usually occurs 3 to 4 weeks after blood vessels have formed and infiltrated the matrix in response to the angiogenic factor present in the matrix.

The matrix compositions described in this invention for repairing the bone portion of a full-thickness defect in joints are also useful in treating any defect in bone tissue as is desirable. Such defects include bone fractures, joint fractures, nonunions and delayed unions, percutaneous arthrodesis, pseudo-arthrosis and bone defects resulting from congenital defects, trauma, tumor infection, degenerative disease and other causes of loss of skeletal tissue. The bone repairing matrix compositions are also useful for prosthesis implantation and enhancement of prosthesis stability, enhancement of osseointegration of implant materials used for internal fixation procedures, stabilization of dental implant materials, healing acceleration of ligament insertion, and spine or other joint fusion procedures.

Fibronectin or any other compound, including peptides as small as tetrapeptides, that contain the amino acid sequence Arg-Gly-Asp, may be used as cell adhesion promoting factors [Ruoslathi et al., Cell, 44, pp. 517-18 (1986)] in order to enhance the initial adhesion of cartilage or bone repair cells to a matrix deposited in a defect site. Fibrin and certain collagen matrices already contain this sequence [Ruoslathi et al., 1986, supra]. When other biodegradable matrices are used, such cell adhesion promoting factors may be mixed with the matrix material before the matrix is used to fill or dress the defect. Peptides containing Arg-Gly-Asp may also be chemically coupled to the matrix material (e.g., to its fibers or meshes) or to a compound added to the matrix, such as albumin.

The compositions hereinbefore described are useful in inducing cartilage or bone formation at a selected site of defect in cartilage or bone tissue of an animal.

The kits and compositions of this invention allow for a treatment of cartilage and bone defects in animals, including humans, that is simple to administer and is restricted in location to an affected joint area. The entire treatment may be carried out by arthroscopic, open surgical or percutaneous procedures.

In using the kits and compositions for treating defects or lesions in cartilage or bone according to this invention, a defect or lesion is identified, prepared, and filled with the matrix compositions according to this invention.

In the case of repairing a defect in bone tissue, an angiogenic factor is present in the bone repair composition at an appropriate concentration to stimulate formation of blood vessels within the matrix filling the bone defect. As blood vessels are formed, the osteogenic factor is released from its delivery system to induce the process of bone formation.

For cartilage repair, a proliferation (mitogenic) agent is present in the matrix composition at an appropriate concentration to stimulate the proliferation of cartilage repair cells in the matrix and defect or lesion. The same agent may also, at this concentration, serve as a chemotactic agent to attract cartilage repair cells, provided that the factor used has a combined effect with respect to cell prolifera-

tion and chemotaxis (as does TGF-β at 2-10 ng/ml of matrix). Alternatively, two different agents may be present in the matrix, one with a specific proliferative effect, and the other with a specific chemotactic effect. In an alternative embodiment, after the defect area is dressed with the matrix, the proliferation agent and, if desired, a chemotactic agent, may be injected directly into the matrix-filled defect area.

In a subsequent step of cartilage repair, the cartilage repair cells in the matrix are exposed to a transforming factor at the appropriate time at a concentration sufficient to transform the cartilage repair cells into chondrocytes which produce stable cartilage tissue. This may be accomplished by including an appropriate delivery system containing the transforming factor within the matrix composition as described above. Alternatively, the transforming agent may be delivered by injection directly into the matrix-filled defect area at the appropriate time. The transforming concentration should be made available to the cells approximately 1 to 2 weeks following the initial implantation of the matrix into the defect area. Additional factors may be added to the delivery system or directly injected in order to better promote synthesis of the cartilage matrix components at this time point.

Cartilage or bone defects in animals are readily identifiable visually during arthroscopic examination of the joint or during simple examination of the lesion or defect during open surgery. Cartilage or bone defects may also be identified inferentially by using computer aided tomography (CAT scanning) X-ray examination, magnetic resonance imaging (MRI) analysis of synovial fluid or serum markers, or by any other procedure known in the art.

The kits and compositions of this invention may be used such that the bone defect site of a full-thickness defect is filled up to the calcified cartilage layer at the bone-cartilage interface with a bone repair matrix composition such that a flat plane is formed. Thereafter, the membrane of the kit, preferably a biodegradable membrane, which is impermeable to cells (e.g., pore sizes less than 5 μm), is placed over the matrix-filled bone defect, and the edges of the membrane sealed to the perimeter of the defect in the region of the cartilage-bone junction. Preferably, the membrane is sealed to the cartilage at the junction by thermal bonding using a thermal knife or laser. The matrix composition comprises a matrix material, an angiogenic factor, and an osteogenic factor, which is packaged in an appropriate delivery system.

The purpose of the membrane is to prevent blood vessels from infiltrating the layer of cartilage in the case of a full-thickness defect. The formation of blood vessels in the cartilage stimulates bone formation in the cartilage and inhibits complete repair of the cartilage layer. If only a bone defect needs to be repaired, no membrane has to be applied.

After the membrane has been placed over the matrix-filled bone defect and sealed to the perimeter of the defect in the region of the cartilage-bone junction, the remaining portion of the defect is completely filled with a matrix composition used to stimulate cartilage repair. The composition for cartilage repair comprises a matrix material and a proliferation agent and, if desired, a chemotactic agent. The composition used in this step may also contain, packaged in an appropriate delivery system, a transforming factor. In the most preferred composition or kit for cartilage repair of the invention, the matrix contains a proliferation agent, a chemotactic agent (which may be identical to the proliferation agent) and a transforming factor which is packaged in or associated with a delivery system that releases the transforming factor, at a time that the repair cells populating the matrix have begun remodelling the intercellular substance, at a concentration that transforms the cartilage repair cells into chondrocytes. Preferred compositions are described above.

The adhesion of a matrix to cartilage in a superficial defect or to the cartilage portion of a full-thickness defect can be enhanced by treating the cartilage defect with transglutaminase [see, e.g., Ichinose et al., J. Biol. Chem., 265 (3), pp. 13411-14 (1990); Najjar, V. A. and Lorand, L., eds. Transglutaminases (Boston: Martinus-Nijhoff, 1984). In this embodiment of the invention, the cartilage defect is dried, e.g. by using cottonoid, and filled with a solution of transglutaminase. The solution is then removed, e.g., by suction, leaving a film containing transglutaminase on the cartilage. The defect is then filled with a matrix composition described above for cartilage repair.

Additional details and examples describing kits and compositions for the treatment and repair of defects in cartilage are described in a commonly owned U.S. patent application, Serial No. 648,274, and are incorporated herein by reference.

In order that the invention described herein may be more fully understood, the following examples are set forth. It should be understood that these examples are for illustrative purposes and are not to be construed as limiting this invention in any manner.

EXAMPLE

Repair Of Full-Thickness Defects In Articular Cartilage

Full-thickness articular cartilage defects, 0.7 mm in width, were created in the medial condyles

and patellar grooves of adult mini-pig knee joints. Lesions were effected in a group of four animals maintained under general anaesthesia, using a planing instrument. The vertical extensions of each lesion into the subchondral bone (containing blood vessels and bone marrow cells) was controlled macroscopically by the occurrence of bleeding to insure that a full-thickness lesion had been made in the joint. The depth of the defect was filled in with a collagenous matrix, containing free TGF-β at a concentration of about 4 ng/ml of matrix solution, and liposome-encapsulated TGF-β at a concentration of about 100 ng/ml of matrix volume. This osteogenic matrix composition was applied up to the cartilage-bone junction, at which level a cellulose membrane (pore size 0.2 μm), well adapted to the perimeter of the cartilage-bone junction of the defect area, was inserted. The remaining defect space was filled up to the surface level of the adjacent articular cartilage with a chondrogenic matrix composition as described in this application at page 15, lines 15-21; page 16, lines 7-11; and page 22, lines 1-17.

About ten weeks after the operation and treatment, the animals were killed and the knee joint components chemically fixed in buffered glutaraldehyde (4%) solutions containing 2.5% Cetyl pyridinium chloride. Following dehydration, in a graded series of increasing ethanol concentration, and embedding in methylmethacrylate, histologic sections were produced and stained with McNeil Tetrachrome and Toluidine Blue O in preparation for light microscopic examination.

That part of the defect space corresponding in level to the subchondral bone, i.e., where osteogenic matrix had been placed, was fully filled with newly-formed bone tissue. Likewise, the defect space adjacent to articular cartilage tissue, i.e., in the region above the cellulose membrane filled with the chondrogenic matrix composition, was filled with articular cartilage repair tissue.

Claims

1. A composition for the treatment of defects in bone comprising:

   a matrix or matrix-forming material used to fill a defect in bone;

   an angiogenic factor at an appropriate concentration to stimulate the formation and ingrowth of blood vessels and associated cells in the matrix and the area of the defect; and

   an osteogenic factor associated with a delivery system and at an appropriate concentration such that upon delivery of the osteogenic factor to cells in the matrix and defect, the cells develop into bone cells which form bone.

2. The composition according to claim 1, wherein the angiogenic factor is selected from the group consisting of bFGF, a mixture of bFGF and heparin sulfate, TGF-β, PDGF, TNF-α, angiogenin, angiotropin or combinations thereof.

3. The composition according to claim 1 or 2, wherein the osteogenic factor is selected from the group consisting of TGF-β, a mixture of a TGF-β and EGF, osteogenin, BMP and combinations thereof.

4. The composition according to any one of claims 1 to 3, wherein the matrix used to fill the defect area is selected from the group consisting of fibrin, collagen, gelatin, agarose, calcium phosphate containing compounds and combinations thereof.

5. The composition according to any one of claims 1 to 3, wherein the angiogenic factor is bFGF present at a concentration of 5-10 ng/ml in the matrix and the osteogenic factor is TGF-β associated with an appropriate delivery system which provides a concentration of TGF-β of 100 ng/ml of matrix solution.

6. The composition according to any one of claims 1 to 3, wherein the delivery system is selected from the group consisting of liposomes, bioerodible polymers, collagen fibers chemically linked to heparin sulfate proteoglycans, carbohydrate-based corpuscles, and water-oil emulsions.

7. A composition for the treatment of defects in bone comprising;

   a collagenous matrix solution;

   basic FGF present at a concentration of 5-10 ng/ml of matrix solution; and

   TGF-β encapsulated in liposomes and present at a concentration of 100 ng/ml of matrix solution.

8. The composition according to claims 1 to 7 for the induction of bone formation at a selected site in bone tissue of an animal wherein the composition is used to fill the site.

9. A kit for treating full-thickness defects in joints in animals which comprises:

   a first matrix containing an effective amount of an angiogenic factor to stimulate formation and ingrowth of blood vessels with associated cells and containing an osteogenic factor associated with a delivery system that releases the osteogenic factor at a concentra-

tion sufficient to induce differentiation of bone repair cells into bone cells which form bone, which is used for filling the bone portion of the full-thickness defect;

a membrane which prevents migration of cells from the bone defect side to the cartilage defect side, which is used for covering the matrix-filled bone portion of the full-thickness defect and may be sealed to the perimeter of the defect in the region of the cartilage-bone junction; and

a second matrix containing an effective amount of a proliferation agent to stimulate proliferation of repair cells, an effective amount of a chemotactic agent to attract repair cells, and an effective amount of a transforming factor associated with a delivery system that releases the transforming factor at a concentration sufficient to transform repair cells into chondrocytes, which is used for filling the cartilage portion of the full-thickness defect.

10. The kit according to claim 9 further comprising transglutaminase which may be used for covering the surface of the cartilage portion of the full-thickness defect prior to dressing the defect or lesion with the second matrix.

11. The kit according to any one of claims 9 to 10 wherein the osteogenic factor, the proliferation agent, and the transforming factor, are TGF-β.

12. The kit according to any one of claims 9 to 11 in which the delivery system for the delivery of the transforming factor and the osteogenic factor is selected from the group consisting of liposomes, bioerodible polymers, collagen fibers chemically linked to heparin sulfate proteoglycans, carbohydrate-based corpuscles, and water-oil emulsions.

13. The kit according to any one of claims 9 to 12 in which the first matrix is selected from the group consisting of fibrin, collagen, gelatin, agarose, and calcium phosphate containing compounds or combinations thereof.

14. The kit according to any one of claims 9 to 13 in which the second matrix is selected from the group consisting of fibrin, collagen, gelatin, agarose, and combinations thereof.

15. The kit according to any one of claims 9 to 14, wherein the first and the second matrix is fibrin which is formed by addition of thrombin to a solution of fibrinogen immediately before filling the defect or lesion with the fibrinogen solution.

16. The kit according to any one of claims 9 to 15 wherein the angiogenic factor is bFGF present at a concentration of 5-10 ng/ml of the first matrix;

the osteogenic factor is TGF-β encapsulated in liposomes and present at a concentration of 100 ng/ml of the first biodegradable matrix;

the proliferation agent and the chemotactic agent are TGF-β present at a concentration of 2-10 ng/ml of the second matrix; and

the transforming factor is TGF-β encapsulated in liposomes and present at a concentration of greater than 200 ng/ml of the second matrix.

17. The kit according to any one of claims 9 to 16, wherein the first and second matrices further contain a cell adhesion promoting factor comprising the tripeptide Arg-Gly-Asp.

18. A kit for treating full-thickness defects in joints of animals which comprises:

a first collagenous matrix containing bFGF present at a concentration of 5-10 ng/ml of the first collagenous matrix, and containing TGF-β in liposomes at a concentration of 100 ng/ml of the first collagenous matrix, which may be used for filling the bone portion of the full-thickness defect;

a membrane, which is impermeable to blood vessels and cells, which may be used for covering the first collagenous matrix-filled bone portion of the full-thickness defect and may be sealed at its perimeter to the edges of the defect in the region of the cartilage-bone junction;

a second collagenous matrix containing TGF-β at a concentration of 2-10 ng/ml of the second collagenous matrix, and containing TGF-β in liposomes at a concentration of greater than 200 ng/ml of the second collagenous matrix, which is used for filling the cartilage portion of the full-thickness defect.

19. The kit according to claim 18 further comprising the step of covering the surface of the cartilage portion of the full-thickness defect with transglutaminase prior to filling the defect with the second collagenous matrix.

20. The composition according to claim 5 or 7 further comprising an amount of heparin sulfate sufficient to enhance the angiogenic activ-

ity of the bFGF.

21. The kit according to claim 16 or 18 wherein the first matrix also contains an amount of heparin sulfate sufficient to enhance the angiogenic activity of the bFGF.

22. The kit according to claim 11 wherein the angiogenic factor is bFGF.

23. The use of the composition in any one of claims 1-8 to prepare a medicament for the treatment of defects in bone.

24. A method of preparing a composition for the treatment of defects in bone comprising:

adding to a matrix or matrix-forming material useful for filling a defect in bone an amount of an angiogenic factor sufficient to stimulate the formation and ingrowth of blood vessels and associated cells in the matrix and area of the bone defect, and an amount of an osteogenic factor associated with an appropriate delivery system which can provide a sufficient concentration of osteogenic factor to stimulate the formation of bone cells.

25. A method for making a kit for treating full-thickness defects in joints in animals comprising:

combining a first matrix or matrix-forming material useful to fill a defect in a bone with an angiogenic factor at a concentration sufficient to stimulate the formation and ingrowth of blood vessels and associated cells in the matrix and area of the bone defect and an osteogenic factor associated with an appropriate delivery system which can provide a sufficient concentration of osteogenic factor to blood vessels and associated cells in the matrix and defect, to stimulate the formation of bone cells;

providing a membrane which can be sealed to the perimeter of the cartilage-bone junction of the full-thickness defect to cover the matrix-filled bone portion of the full-thickness defect and prevent the migration of cells from the bone defect side to the cartilage defect side of the full-thickness defect; and

combining a second matrix or matrix-forming material useful to fill the cartilage portion of the full-thickness defect with a proliferation agent at a sufficient concentration to stimulate proliferation of repair cells in the cartilage portion of the full-thickness defect, and a chemotactic agent at a sufficient concentration to attract repair cells to the matrix in the cartilage portion of the full-thickness, and a transforming factor associated with an appropriate delivery system which can provide a sufficient concentration of the transforming factor to stimulate the formation of cartilage from the repair cells in the matrix-filled cartilage portion of the full-thickness defect.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 11 5079

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	WO-A-9 005 755 (COLLAGEN CORP.) * Page 11, lines 12-34; claims * ---	1-25	A 61 L 25/00 A 61 L 27/00 A 61 K 37/02
X	EP-A-0 308 238 (ETHICON INC.) * Page 3, lines 49-55; claims * ---	1-25	
X	EP-A-0 361 896 (COLLAGEN CORP.) * Claims * ---	1-4,6,8,10	
X	EP-A-0 375 127 (GENENTECH, INC.) * Column 10, lines 28-42; examples 1-3 * ---	1-4,6,8,10	
X	ANNALS OF SURGERY, vol. 211, no. 3, March 1990, pages 288-294, Philadelphia, PA, US; G.A. KSANDER et al.: "Exogenous transforming growth factor-beta 2 enhances connective tissue formation and wound strength in guinea pig dermal wounds healing by secondary intent" * Abstract; discussion * ---	1-4,6,8,10	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
X	WO-A-9 009 783 (MASSACHUSETTS INSTITUTE OF TECHNOLOGY) * Page 5, lines 25-31; page 6, lines 1-31; page 7, lines 1-5 * ---	1-4	A 61 L A 61 K
D,P X	WO-A-9 213 565 (R.F. SHAW) * Whole document * --- -/-	1-25	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-12-1992	ESPINOSA Y CARRETERO M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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D : document cited in the application
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EUROPEAN SEARCH REPORT

Application Number

EP 92 11 5079

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
A	WO-A-8 904 646 (S.R. JEFFERIES) * Examples 2-3 *	1-10	
A	WO-A-8 600 526 (A.I. CAPLAN)		
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	09-12-1992	ESPINOSA Y CARRETERO M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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